

# Westinghouse Lighting Institute

GRAND CENTRAL PALACE, NEW YORK

# GENERAL ILLUMINATION COURSE

JANUARY 1930

ASSIGNMENT No. 3

CONTENTS

PRINCIPLES OF LIGHT CONTROL



WESTINGHOUSE LAMP COMPANY

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ENGINEERING AND TECHNICAL DATA PREPARED
BY THE COMMERCIAL ENGINEERING DEPT. OF THE
WESTINGHOUSE LAMP CO., BLOOMFIELD, N. J.

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# PRINCIPLES OF LIGHT CONTROL

upon the manner in which it is used. To illustrate, a pair of properly adjusted automobile headlights will provide good illumination on the road making it possible for a car to be driven rapidly and safely on even the darkest night. Headlights which are indispensable to the driver of a car can be blinding to the driver of an approaching car particularly when they are not properly adjusted. This obvious example shows the necessity for the proper control of light in order that it may be an aid and not a hindrance to vision. Blinding effects or "glare" are present whenever unshaded lamps are suspended in the line of vision.

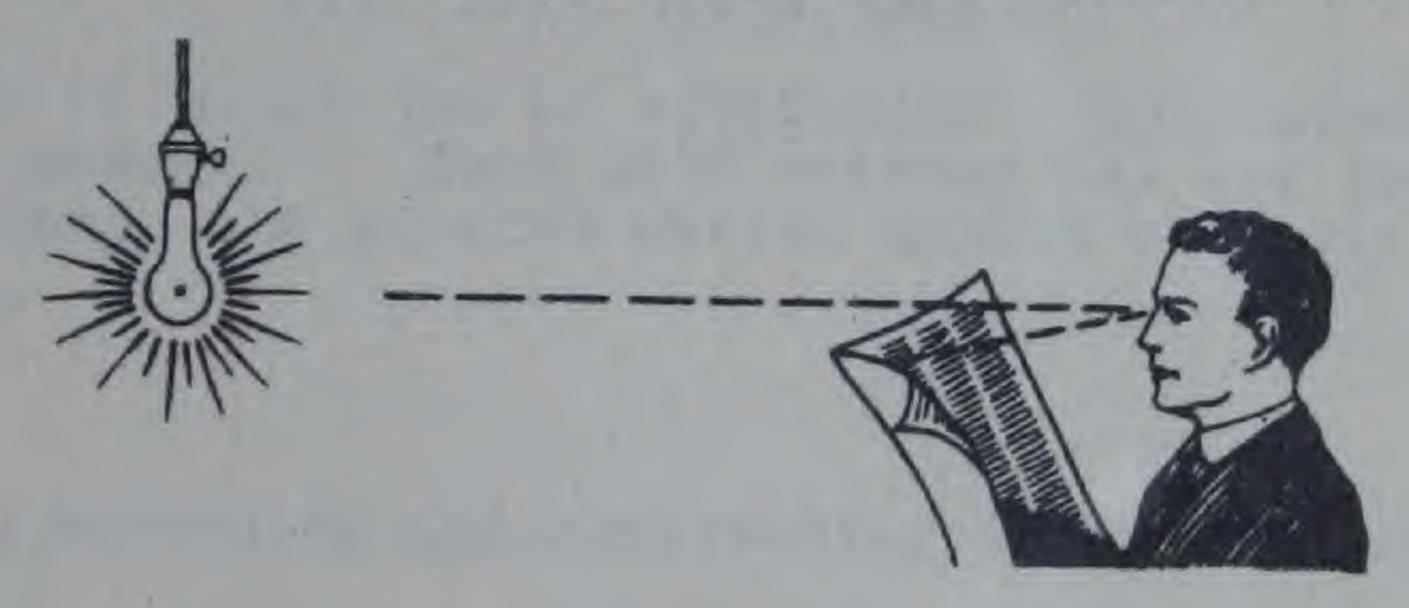


Fig. 20 - "Glare" defeats vision

Unshaded light sources in the field of vision cause continuous conflict of the working parts in the eye. Glaring light coming directly from the source to the eye opposes vision while light coming directly from the source to an object or plane upon which the eye is focused, tends to make vision easier. Dazzling light is commonly called glare.

Light from artificial illuminants is usually emitted toward the ceilings and side walls and into the eyes, rather than downward to the working planes where it is most useful. It cannot be employed effectively without the use of reflectors or enclosing glass-ware. The art of illuminating engineering makes use of known scientific





principles to convert light into illumination, that is, to shade, and direct the light to those points where it is most needed, and reduce the dazzle or glare to a minimum. In general, the light-giving element, as for example the filament of an incandescent lamp, should be screened from view.

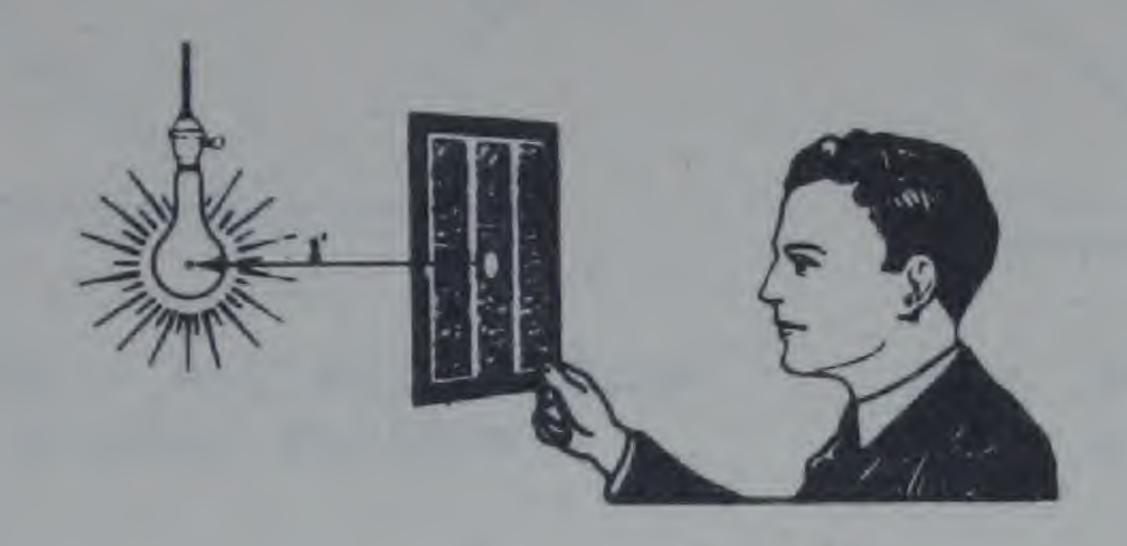


Fig. 21 - Glare Test

The effect of glare can be strikingly illustrated in the above manner: When held between the eye and an unshaded lamp, the printed matter around the hole is illegible.

In screening and redirecting light, transparent, translucent and opaque substances are used. Transparent substances allow
most of the light to come through without scattering it, and permit
objects to be clearly seen through them. Translucent substances allow
some of the light to come through, but scatter it so that objects cannot
be clearly distinguished through them. Opaque substances allow no
light to come through them and cannot be seen through. These three
substances differ widely in their properties, varying from almost perfect
transparency to complete opacity.

#### Reflection

Reflected light is light redirected by a surface, much as a tennis ball is redirected when it comes in contact with a racket.

Polished metal and mirrored surfaces are frequently used for the redirection and reflection of light. As illustrated in Figs. 22 and 23, the light rays striking the surface at an angle are





reflected in the direction a-b making the two angles x (Angle of Incidence) and y (Angle of Reflection) equal. This is called the law of reflection.

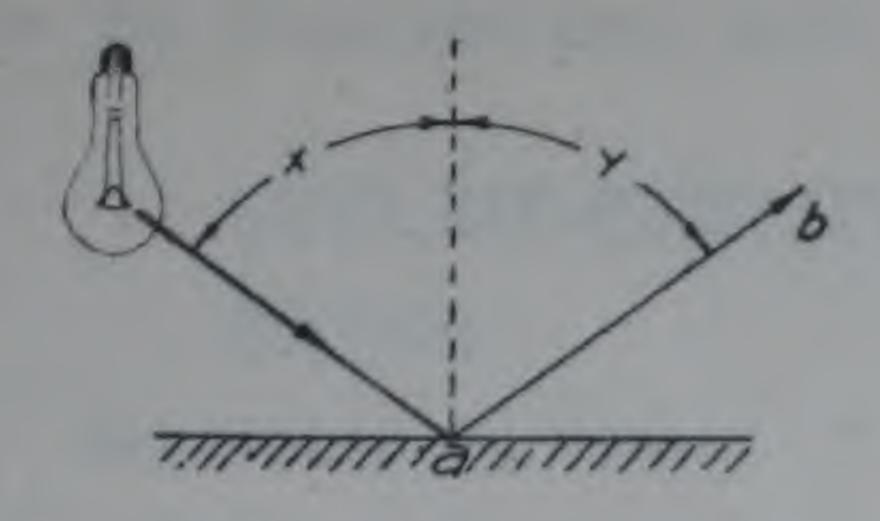


Fig. 22 - Reflection from polished surface

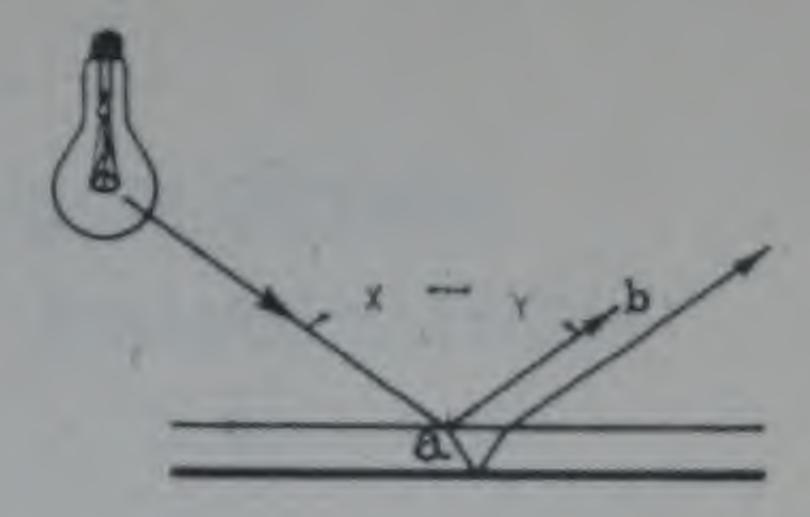


Fig. 23 - Reflection from mirror surface

A surface with a dull finish, such as aluminum paint, reflects light in the same general manner as a polished surface but spreads the rays somewhat as indicated in Fig. 24. This is known as mixed reflection. On the other hand a rough matt surface, such as white blotting paper, Fig. 25, completely diffuses the light; the rays are reflected and re-reflected by the fibres in such a way that they are dispersed in all directions. With completely diffusing surfaces such as this the highest intensity of reflected light is always perpendicular

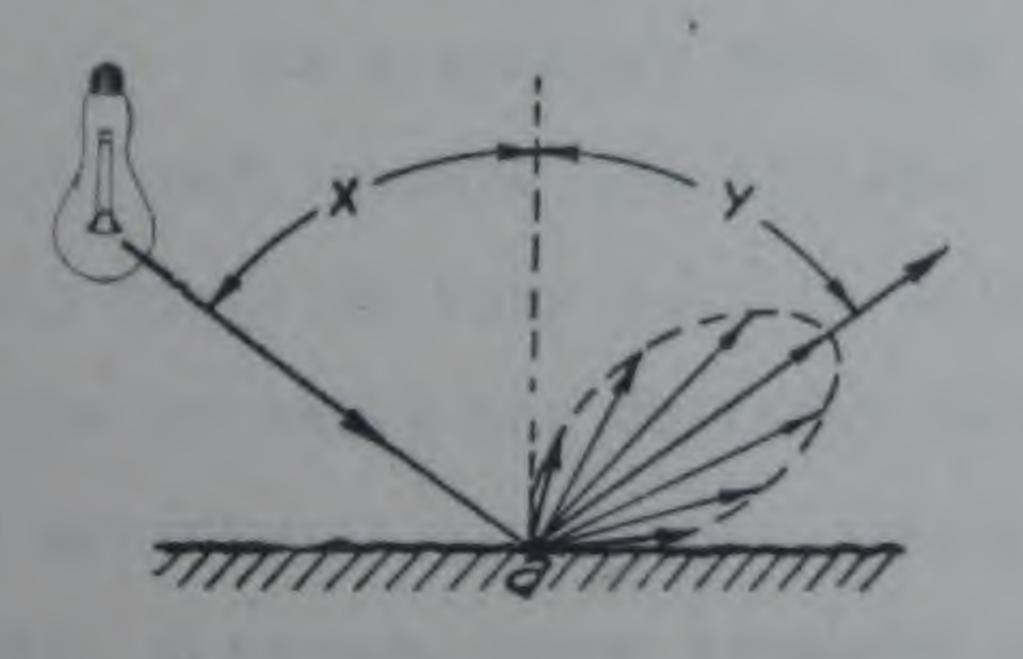


Fig. 24 - Reflection from dull finish surface

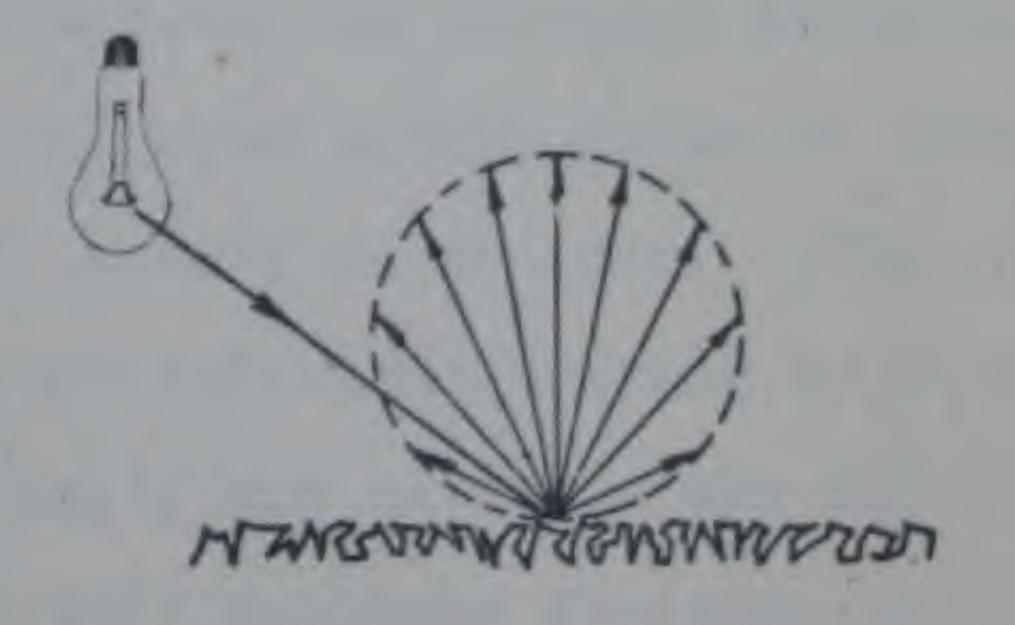


Fig. 25 - Reflection from rough matt surface

to the surface. Partially or completely diffuse-reflecting surfaces, such as porcelain enamel and matt surface paint of light tones, have a wide application in lighting practice. By properly diffusing and reflecting the light, such surfaces minimize glare and produce an even illumination without dense shadows.





The following table shows the percent of light reflected from various typical surfaces including those most generally used for lighting equipment. Technically this percentage is known as the "Reflection Factor" and is defined as the ratio of the flux reflected by a body to the flux incident upon it.

## LIGHT REFLECTED FROM VARIOUS SURFACES

Surface	Reflection Factor
Magnesium Carbonate	0.98 - 0.99
Polished Silver	0.92
White Blotting Paper	0.80 - 0.85
Mirrored Glass	0.82 - 0.88
White Paint	0.75 - 0.80
Polished Chromium	0.65
Porcelain Enamel	0.60 - 0.70
Polished Aluminum	0.62
Aluminum Paint	0.62
Polished Nickel	0.55
Black Paint	0.03 - 0.05

As a general rule, in planning the interior decoration of a room, wall papers and finishes that have a high gloss or that are extremely light or very dark in color, should be avoided. The reflecting properties of walls and ceilings have an important bearing on both natural and artificial lighting. Light walls and ceilings are usually desirable, although large expanses of wall surfaces finished in colors that reflect a large volume of light into the eyes, are objectionable in any room where the occupants are required to sit directly facing the walls for considerable periods of time. Most types of lighting units direct light in such a way that sidewalls at eye level and below are illuminated to somewhat less than one-half the intensity of the working





plane\*. The brightness of a wall is controlled by: (1) the amount of light it receives, and (2) its reflection factor. It has been found that for comfortable lighting the wall brightness should not be more than 25% of the brightness of white paper on the horizontal working plane.

Walls finished in buff, light green, or light gray reflect the proper proportion of light. Walls finished in a high gloss are very likely to cause harmful glare; the use of so-called matt or semimatt finishes is recommended.

#### Transmission

Another form of light modification is accomplished by means of diffusing glass. As a stream of water from a garden hose directed through a very fine wire screen is scattered in all directions, so a piece of frosted or opal glass will scatter or diffuse light in all directions. The screen not only breaks up the stream of water passing through it, but also actually turns some of it back; diffusing glass (Fig. 27) does the same with light. If more than half of the light is transmitted through the glass it may be said to be of light density; if the transmission is less than one half; the glass is of heavy density.

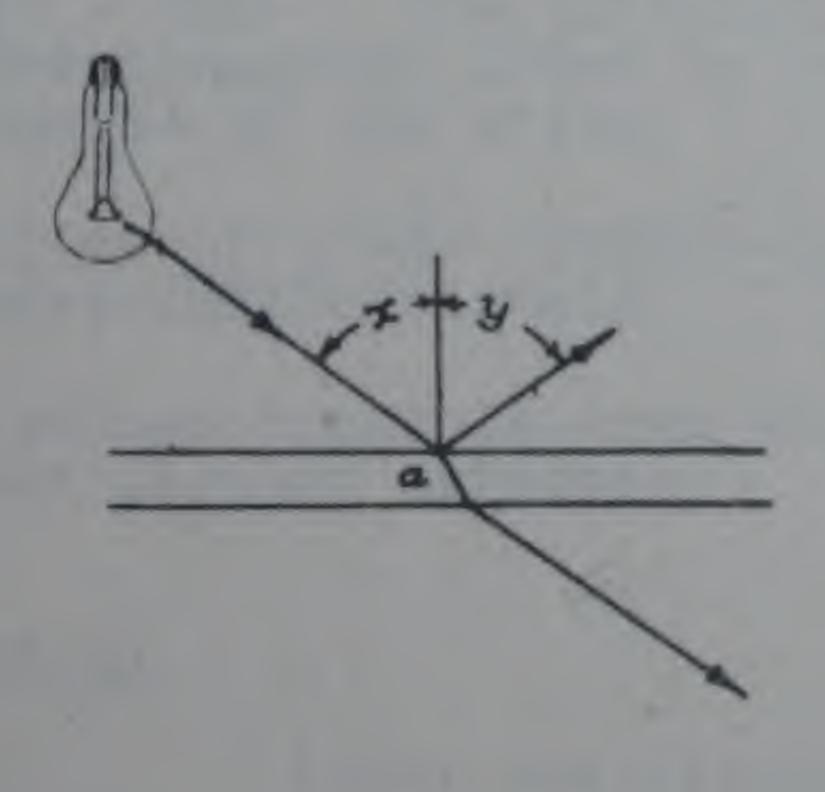


Fig. 26 - Transmission and reflection of clear glass

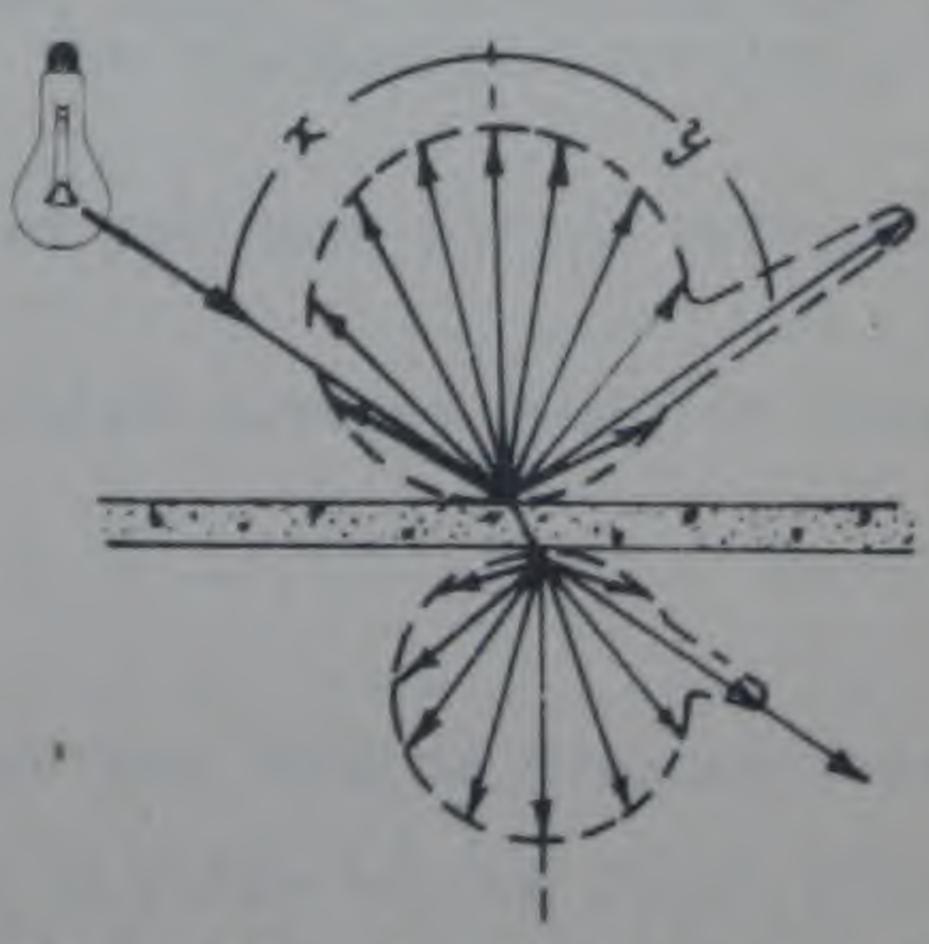


Fig. 27 - Transmission and reflection of opal glass

A theoretical horizontal plane. It is usually assumed as 30 inches above the floor, the average level at which work is ordinarily performed.





Even with clear glass which does not diffuse light rays which pass through it there is an absorption and a surface reflection as shown in Fig. 26. This reflected light increases considerably as Angle X is increased.

## TRANSMISSION OF LIGHT

Type of Glass	Percent Light Transmitted
Clear	80 - 90
Frosted	75 - 85
*Figured or Ribbed Crystal	70 - 85
**Light Density Opal	55 - 70
***Heavy Density Opal	10 - 45
+ Amber	45
+ Red	15
+ Green	10
† Blue	5

- \* Types of glass ordinarily used in windows of industrial plants.
- \*\* Type of glass ordinarily employed for enclosing globe luminaires The overall efficiency of luminaires made of opal glass varies from
  80 85%. The difference between these efficiencies and the transmissions given above is caused by the surface reflections from the
  inside of the globe.
- \*\*\* Types of glass ordinarily employed for open bottom reflectors and semi-indirect bowls.
  - + Average transmissions through colored glasses used for theatrical and display purposes.

#### Refraction

Light modification of another form is demonstrated by the apparent shortening and the bending of a stick at the point where it enters the water. (See Fig. 28). This phenomenon is termed refraction. This is due to the light that is reflected from the stick under the water passing through two substances, water and air, before it strikes the eye.





When a beam of light is projected obliquely on the surface of water (Fig. 29), all parts of the light beam do not enter the water at the same time. The part of the beam represented by d enters before

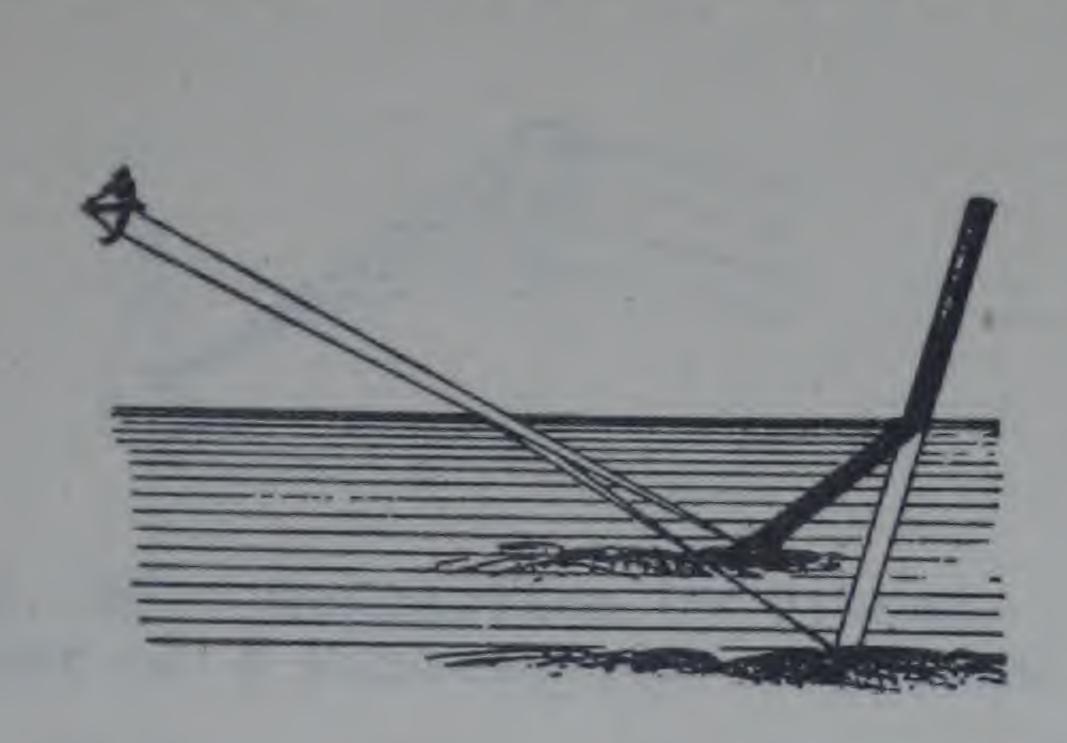


Fig. 28 - Stick partly in water appears shortened and broken.

Fig. 29 - Diagram of light beam subject to refraction.

water, the light beam changes direction to the position indicated by B-C in the water. The extent of this change or refraction depends upon the ratio of velocity of the light passing through air and water. The ratio between the speed of light through air to the speed of light through a second medium is termed the index of refraction of that medium.

Indexes of refraction for various substances are shown

below:

Water	1.33	Crown Glass	1.53
Alcohol	1.36	Flint Glass	
Turpentine	1.47	Diamond	

The high index of refraction of the diamond accounts for its great brilliancy.

The principle of refraction is utilized in lenses, ribbed window glass, and numerous prismatic lighting fixtures to divert light rays from their original path somewhat in the manner illustrated in Fig. 30. Here the glass is so designed that a double refraction is secured, the light rays being bent downward both on entering and on leaving the glass.





Glass prisms may be used to redirect light as are polished metal or mirrored surfaces. Fig. 31 shows the path of a single light

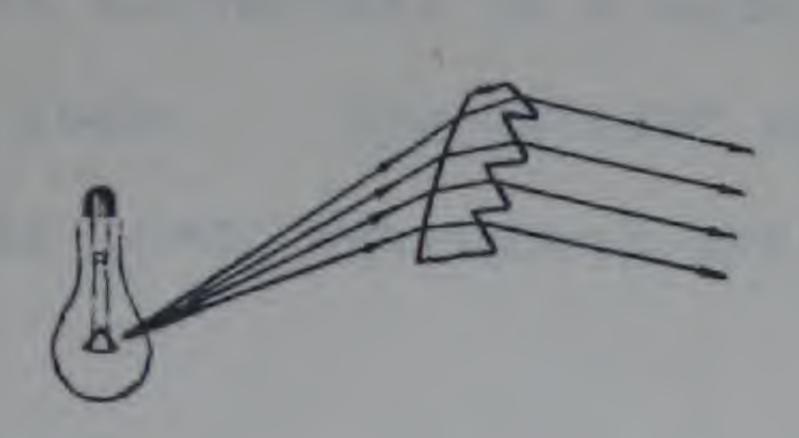


Fig. 30 - Refraction by ribbed glass or a combination of prisms.

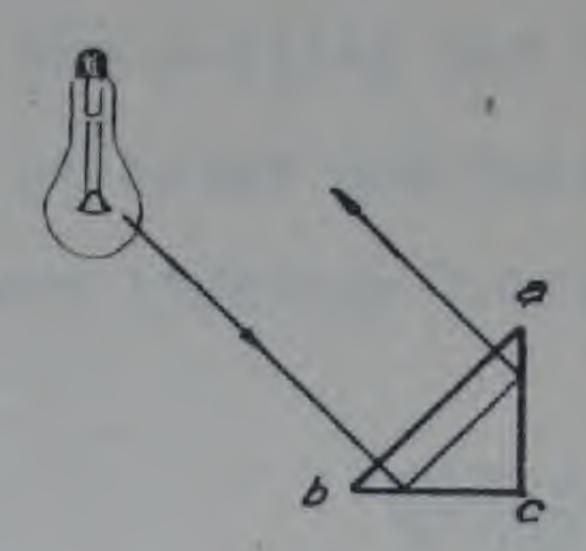


Fig. 31 - Reflection by prism.

ray redirected by a prism. The ray strikes the surface b-c at an oblique angle and at such an angle the high index of refraction of glass prevents the escape of the light through the surface and reflects it to the surface c-a where the same phenomenon takes place. The ray finally passes out through the surface a-b. By tilting the prism the direction of the redirected beam can be accurately controlled.

#### LIGHTING EQUIPMENT

In the design of lighting equipment the reflecting, refracting and diffusing properties of many different materials are used to accomplish specific illumination results. The use of any accessory with a lamp involves some loss of light by absorption. This is usually more than compensated for by the gain in diffusion and in the amount of light that is directed to useful areas.

An example of accurate light control is the searchlight, where by means of reflections from polished metal or mirrored glass, the light is concentrated into a narrow beam with sufficient candlepower to furnish illumination at great distances. Such accurate control and concentration of light is not needed for ordinary illumination problems. For example, an RLM dome shaped metal reflector, as shown among the units in Fig. 32, has a porcelain enamel surface and may be





satisfactorily used to reflect light in a general downward direction. A similar reflector of translucent glass will direct the bulk of the light downward and, in addition, will allow sufficient light to pass through the glass to illuminate to a moderate degree the ceiling and upper side walls of a room. Luminaires\* which direct at least one-half of the light in the lower hemisphere are termed direct lighting luminaires.

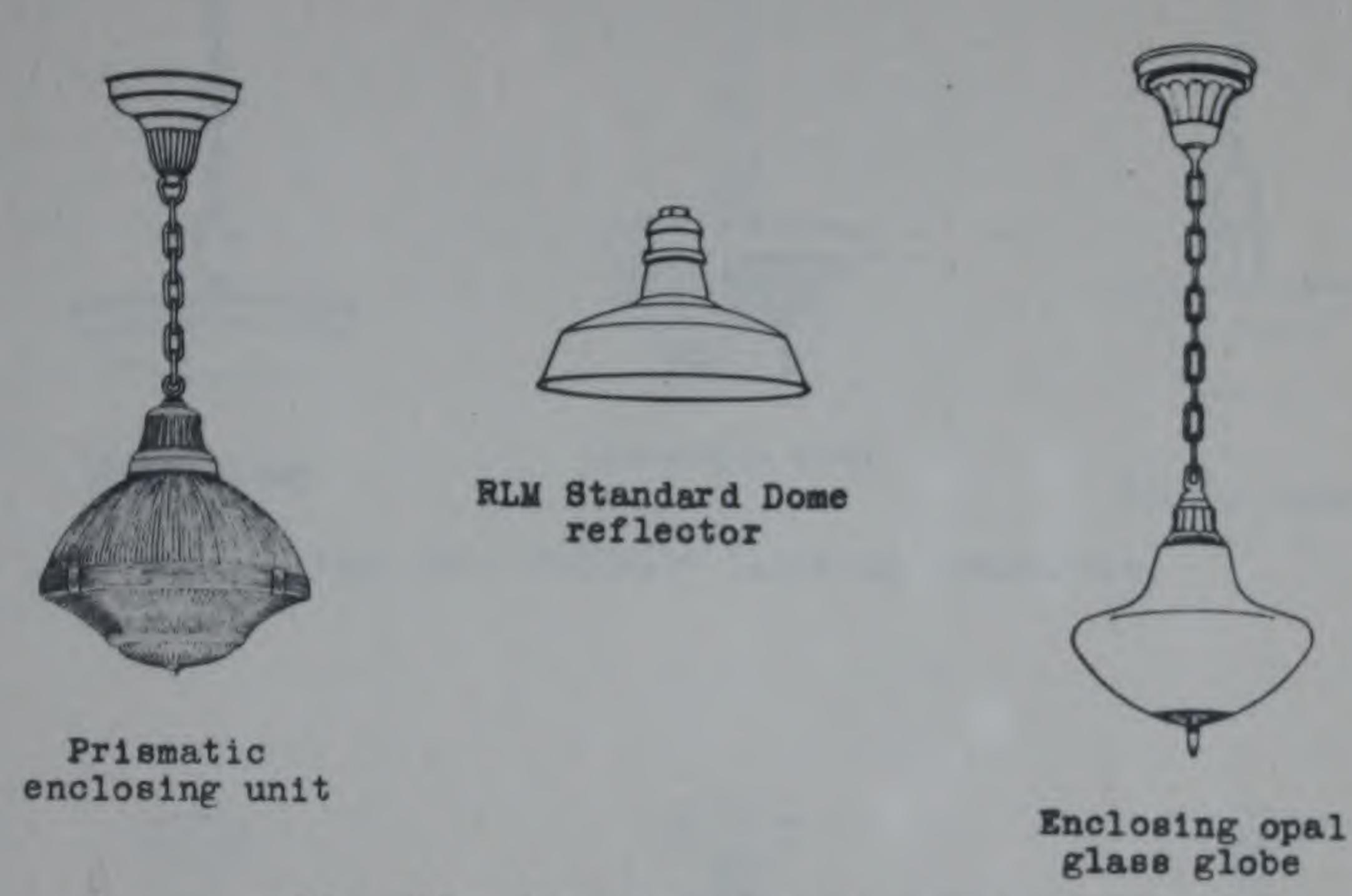


Fig. 32 - Direct lighting luminaires.

Several types are illustrated in Fig. 32. The efficiency of direct lighting luminaires is generally greater than for semi-indirect or totally indirect luminaires operating under similar conditions. However, the likelihood of glare or glaring reflections is somewhat greater. This characteristic has led to the development of the enclosing glass type of luminaire which completely conceals the lamp filament and which diffuses and distributes the light more effectively. With open reflectors, direct glare from lamp filaments and other light reflections

<sup>\*</sup>Luminaire is the term now applied to lighting units of all types which in the past have generally been called lighting fixtures.





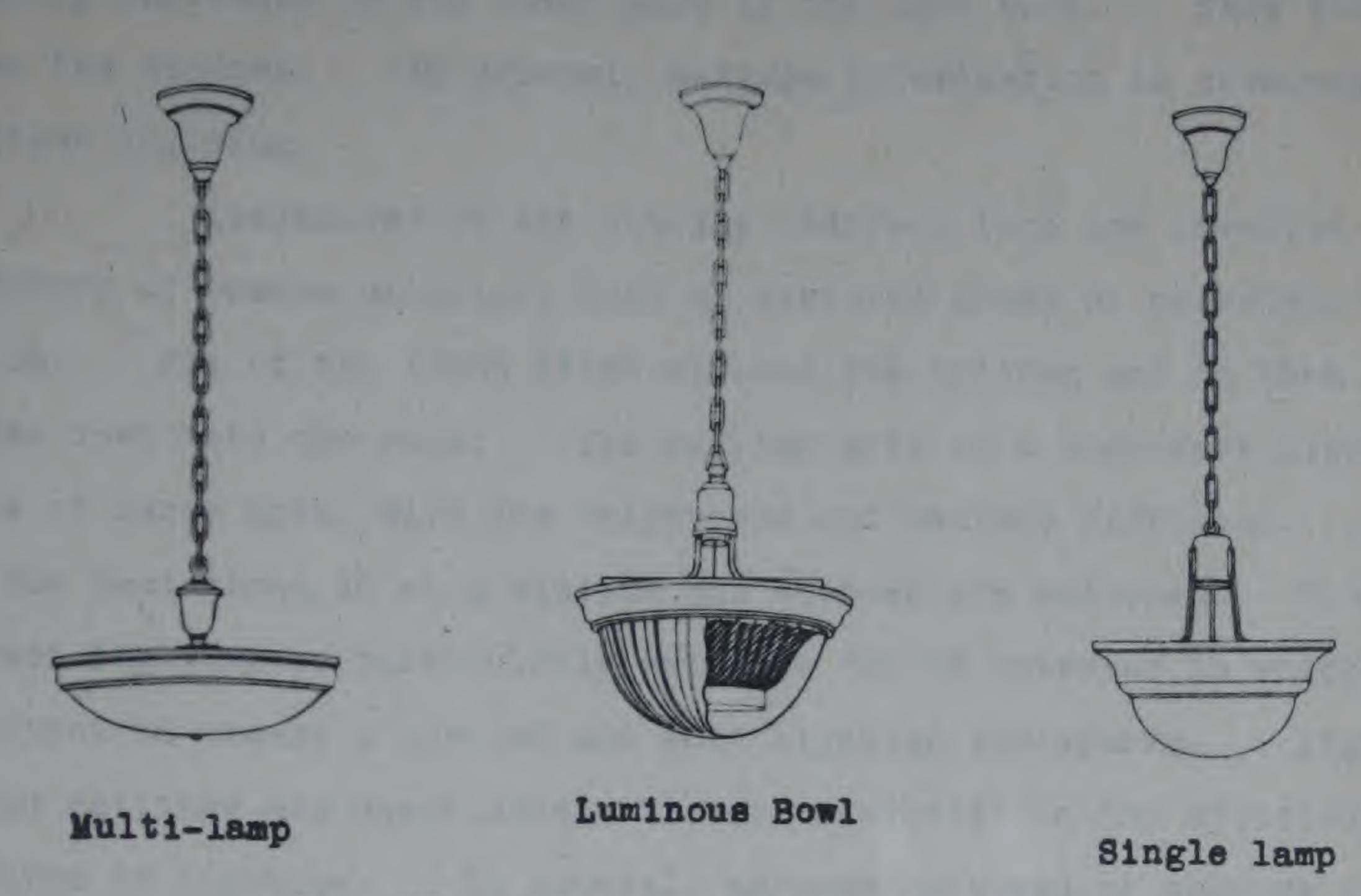


Fig. 33 - Indirect lighting luminaires.

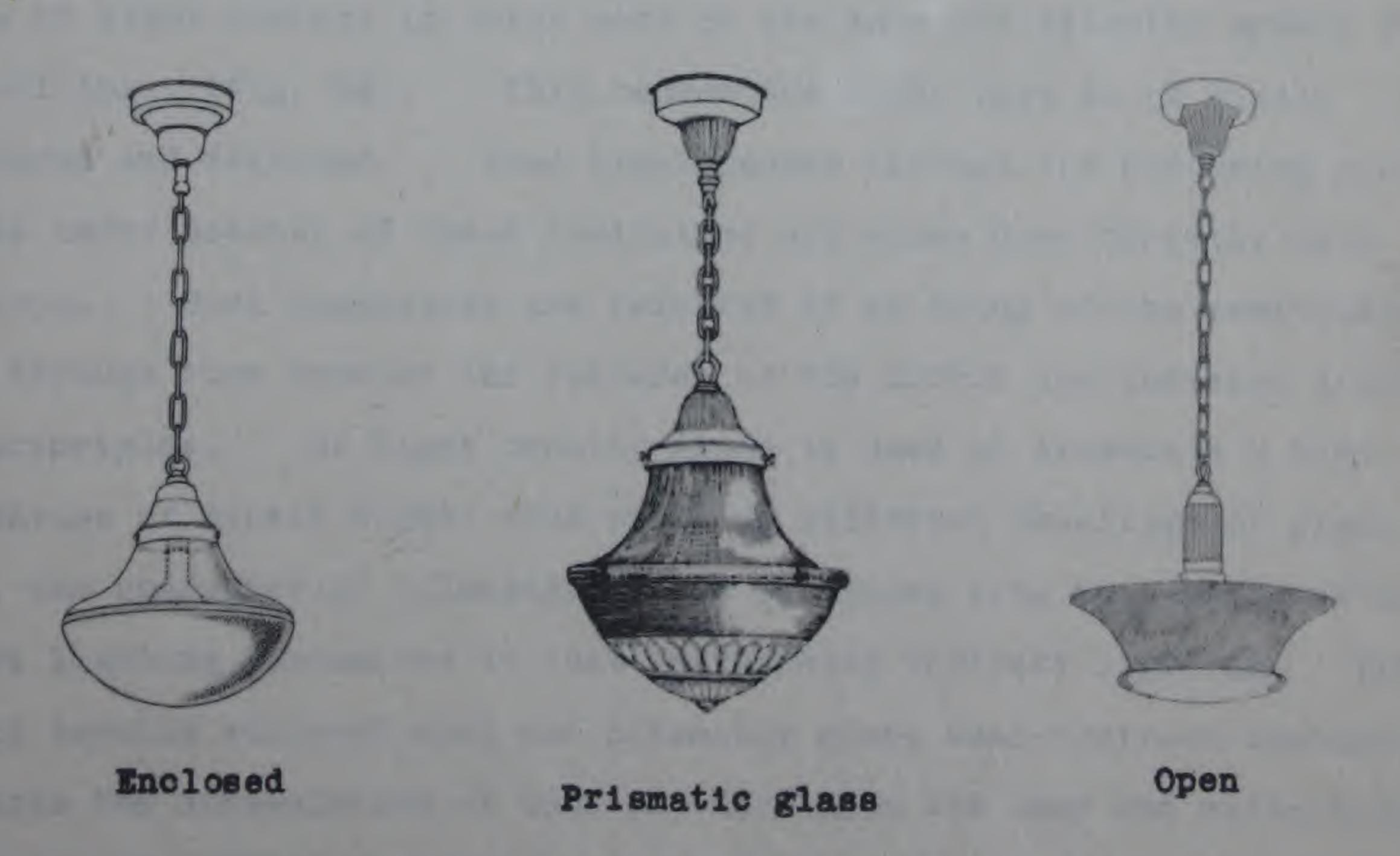


Fig. 34 - Semi-indirect lighting luminaires.





are minimized by the use of a large diameter reflector and a coating of diffusing substance on the lower part of the lamp bulb. This tends to soften the shadows. In general, maximum illumination is obtainable by direct lighting.

Luminaires of the totally indirect type are inverted reflectors of opaque material, such as mirrored glass or porcelain enamel, Fig. 33. All of the light first strikes the ceiling and is then reflected down into the room. The ceiling acts as a secondary light source of large area, with low brightness and maximum diffusion. Glare from the luminaires is at a minimum and shadows are softened. Totally indirect lighting is particularly suitable for an interior in which it is desired to create a subdued and soft lighting atmosphere. Light colored ceilings and upper side walls are essential to the efficiency of this type of lighting. In general, maximum softness of shadows is obtained by indirect lighting.

Inverting a reflector of diffusing glass provides another means of light control in which most of the rays are directed upward to the ceiling. (Fig. 34). This causes the light rays to be widely scattered and diffused. Some light passes through the diffusing glass of the under section of these luminaires and comes down directly into Such luminaires are referred to as being of the semi-indirect the room. type because they combine the features of the direct and indirect lighting principles. If light density glass is used it transmits a high percentage of direct light; thus by using different densities of glassware, the character of illumination can be varied from that produced by direct lighting luminaires to that approaching indirect lighting. The use of totally enclosed opal and prismatic glass semi-indirect luminaires prevents the accumulation of dust and dirt upon the lamp and reflecting surfaces and greatly facilities maintenance.

It is apparent from the foregoing that the manner of controlling light is all important. For our daily needs it is not





enough to supply raw, uncontrolled light - it must be diffused, deprived of its dazzling effect and directed toward the objects to be illuminated. The choice of lighting equipment depends upon the particular conditions which have to be met.

## QUESTIONS

- 1. Explain briefly the cause of glare.
- 2. How may we prevent glare from a bare lamp?
- 3. What three classes of substances are employed for screening and redirecting light? Describe each.
- 4. What is meant by Reflected Light? What is the Law of Reflection? Show by diagrammatic sketches the application of this Law to a light ray striking (a) a polished surface; (b) a mirrored glass; (c) a dull finished surface.
- 5. Name the three classes of luminaires and explain the light control features of each. Which of these classes of luminaires is the most efficient? Why? What class necessitates least maintenance? What class requires frequent cleaning? Why?

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# The Mercury-Vapor Lamp

Another lamp, widely used for photographic purposes and to some extent for industrial lighting, is the Mercury-Vapor lamp, which can be recognized by the characteristic bluish green color of the light. This lamp consists of a long glass tube from which the air has been exhausted and which contains a small amount of mercury in a bulb at one end. An electrode is sealed into the glass at either end of the tube. The arc is started by tilting the tube slightly until a thin stream of mercury completes the circuit between the terminals. Returning the tube to its normal position breaks the circuit as the mercury runs back into the bulb and draws an arc behind it. The heat of the arc soon vaporizes enough mercury to fill the tube and it becomes luminous throughout its entire length. The peculiar color of the light is due

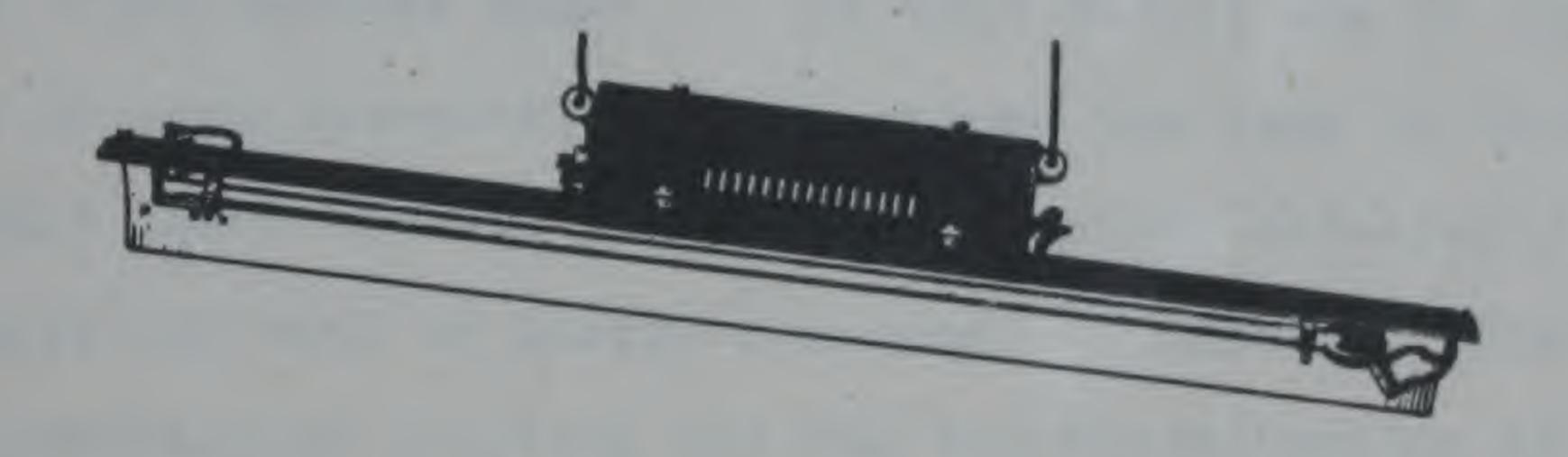


Fig. 7 - Mercury Vapor lamp

and to the absence of red rays. Since photographic emulsions are most sensitive to green and blue, the mercury vapor arc is an efficient illuminant for photographic purposes.

#### The Neon Tube

when an electric current is forced through certain gases, they become luminous. Neon, one of the rare elements of the atmosphere, is a gas of this type which glows with a rich orange-red light. The Neon tubes used in electrical advertising operate on this principle.









GRAND CENTRAL PALACE, NEW YORK

# GENERAL ILLUMINATION COURSE

JANUARY 1930

ASSIGNMENT No. I

CONTENTS

GENERAL INSTRUCTIONS
FOREWORD
LIGHT SOURCES



WESTINGHOUSE LAMP COMPANY

FOR SURVEY SURVE

BY THE COMMERCIAL ENGINEERING DEPT. OF THE WESTINGHOUSE LAMP CO., BLOOMFIELD. N. J.



# GENERAL INSTRUCTIONS

Answers to the questions appearing at the end of each assignment, and requests for further information should be sent to the Westinghouse Lighting Institute, Grand Central Palace, New York, N.Y. All written material must be submitted on plain white standard stenographic paper, preferably typewritten, otherwise neatly written in ink. No manuscripts will be accepted if written in pencil or on any paper other than the above.

The first page of each set of assignment questions should be headed as follows: Assignment number in the upper left hand corner; your name in the upper right hand corner; and directly below your title or department, your company's name and address. Additional sheets of answers must be securely fastened to the first page.

The reference number of each question should appear in the margin to the left of the answer. To obtain full credit, answers must be mailed not later than seven days after receipt of each assignment. Provided answers have been received, a new assignment will be mailed to the student on the first day of each week.





# FOREWORD

On a purely monetary basis it is rated by insurance companies on a par with the arms or legs as a means of earning a livelihood; on any other basis it is priceless!

Like a great many other organs of the human body, the eyes will withstand a considerable amount of abuse without apparent complaint. This fact presents a grave danger and unquestionably the greatest obstacle for the illuminating engineer to overcome. If eyes went temporarily blind or offered some other vigorous protest against abuse, the task of selling good illumination would be quite simple; but the effects of eye strain are so insidious that they usually pass unnoticed until irreparable damage has been done.

The science of illumination, therefore, has a humanitarian value in the conservation of eye-sight as well as a utilitarian value in promoting the economic welfare of the race.

It is the purpose of this course to familiarize the student with the fundamental principles of illumination, the common sources of artificial light, and the equipment and methods of utilizing it to the best advantage.





# ANCIENT ILLUMINANTS

It may be said that the history of artificial illumination began with the discovery of fire because, by picking up one of the burning embers, man learned the use of the torch - really a portable lamp which he later constructed of such materials as fagots or knots of resinous wood. Natural fats and wax replaced the wood of the torch, until, with the discovery and development of the wick, the use of oils for fuel was possible. Solidified oils and fats in combination with the wick formed the more convenient candle. Whale oil and similar organic fuels were not generally superseded by mineral oil (petroleum) before the middle of the nineteenth century.



A - Torch, B - Stone lamp (3000 B.C.), C - Pottery lamp (200 A.D.)

D - Bronze lamp (1000 A.D.), E - Flemish oil lamp (1600),

F - Candle (1800), G - Kerosene oil Lamp (1870).

Fig. 1 - Ancient Lamps

The first marked scientific improvement came during the latter part of the nineteenth century when a chimney was added to the oil lamp. The draft thus afforded resulted in more complete combustion of the fuel and produced a cleaner, more brilliant flame.

argued 1787 ( Palaz - p-111)





General Illumination Course Assignment 1, Page 4

## GAS LIGHTING

Natural gas exists mainly in the petroleum bearing area of the country, notably in Pennsylvania, West Virginia, Ohio, California, Texas, Oklahoma and Indiana. In a few instances it was used for illuminating purposes as early as 1821, but at that time its value as a source of light and heat was not generally recognized.

Artificial gas is produced by distilling soft coal. In this process there are formed coal gas, coal tar and water containing ammonia and other by-products in solution. The method of generating coal gas is illustrated graphically in Fig. 2. The coal is charged

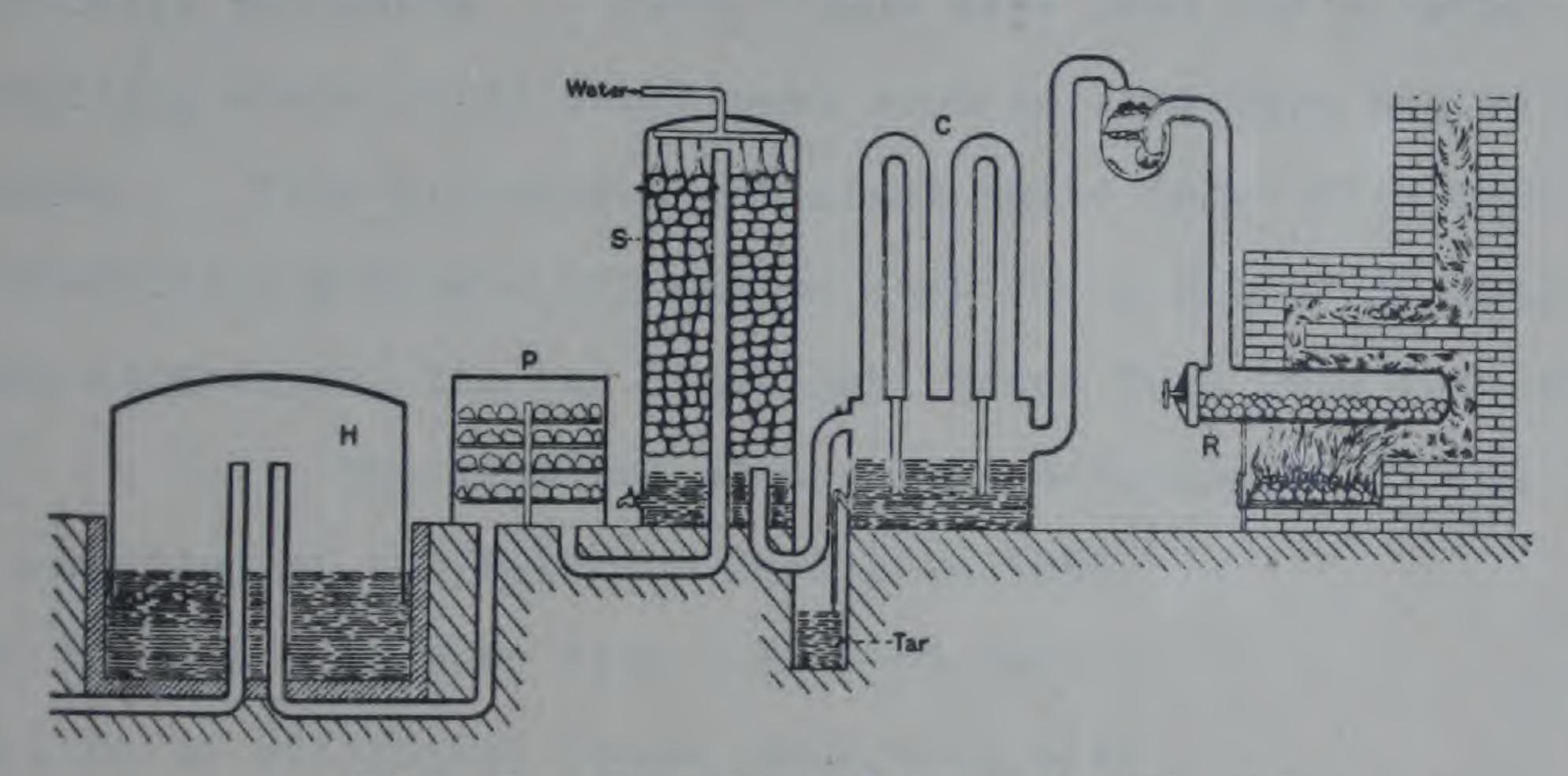


Fig. 2 - Diagram of a coal gas plant

and vapors pass off through the condensers C, in which the tar is condensed, and into the scrubber S, where the gas is washed with water to remove ammonia and other by-products. It then goes through layers of iron oxide in the purifiers P, where sulphur compounds are removed. Finally, the gas enters the holder H from which it is distributed through gas mains to the community.

The use of gas for lighting afforded an advantage over earlier illuminants in that it could be supplied from a central source and piped to the premises of the consumer. With the use of gas,





lighting equipment became "fixtures", whereas up to that time they had generally been portable.

In the earlier gas and oil lamps, the light was emitted

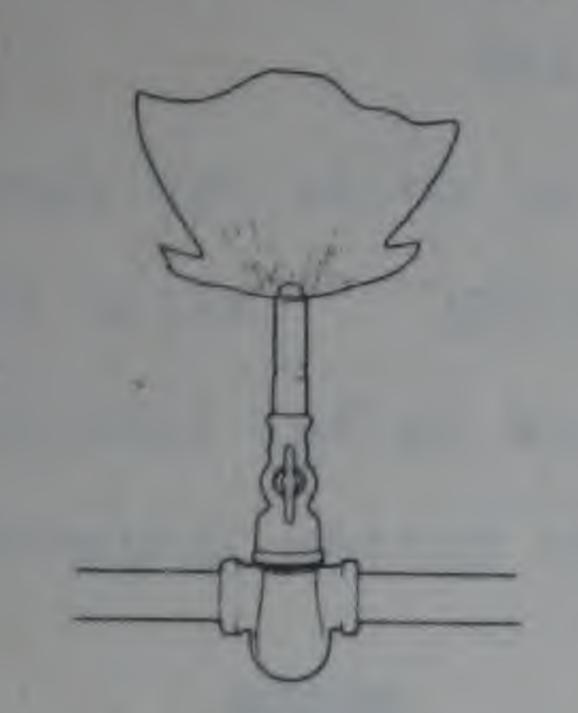


Fig. 3 - Open flame gas burner

by solid incandescent particles of carbon in the flame itself. If these particles passed out of the flame without being consumed, the flame smoked and the particles formed lamp-However, when gas is first mixed with black. air so that plenty of oxygen is available, the carbon particles are entirely consumed and furnish additional heat. The flame is then

practically invisible. Such flames were used for a later development of lighting where solid substances such as lime were heated to incan-This produced a brilliant white light of a quality desirable descence. for theatrical purposes and was so used for a number of years. common expression, "in the limelight" arose from this form of illumination.

The greatest step in the development of gas lighting was the invention of the Welsbach mantle in 1886. These mantles were made from a knitted fabric of cotton or artificial fibre, saturated with a solution of certain salts and oxides of thorium and cerium. When first ignited, the organic material of the mantle burned away leaving the ash in the original form of the When heated the mantle became highly fabric. luminous and produced a much whiter, more efficient source of light than the open flame

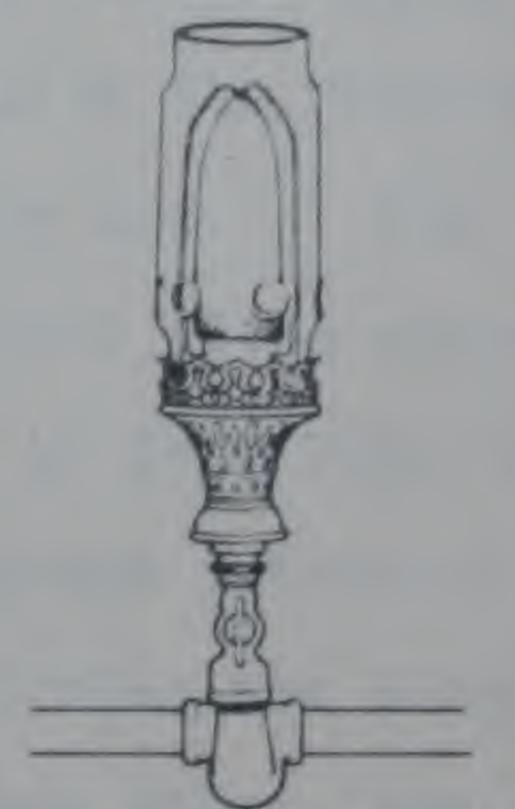


Fig. 4 - Welsbach mantle

gas burner. The Welsbach mantle is still in general usage where gas is the only source of illumination.





## ELECTRIC LIGHTING

# The Electric Arc Lamp

Sir Humphrey Davy in 1809 demonstrated the first electrical arc which he had discovered while experimenting with a battery of 2000 cells. About ten years before, Alesandro Volta, an Italian professor (after whom our electrical term "volt" is named), discovered a chemical method of obtaining electricity, the forerunner of our modern



Fig. 5 - Electric arc between carbon terminals.

dry batteries. Davy, working with the battery which he had constructed after Volta, found that by connecting the terminals to two pieces of charcoal, touching them together and pulling them apart again, he could produce an intense white light. Not only did the charcoal terminals become luminous but also

the crescent shaped stream of gas connecting them. From this latter action the term "arc" is derived.

To operate an arc lamp, the electrodes, across which the arc is maintained, must first be brought together to allow the current to start to flow and then be separated so as to draw the arc. The carbon points become extremely hot when sufficient current flows across the gap, the positive electrode reaching a temperature of from 3000 to 3500 degrees Centigrade (approximately 5400 to 6300 degrees Fahrenheit). At this temperature the carbon evaporates and the electrodes are slowly consumed. If they are not moved constantly toward each other, the arc becomes longer and longer until the current is finally broken.

To make a practical arc lamp it was, therefore, necessary to devise a mechanism which would -

(1) Bring the carbon points together when no current was flowing in the circuit.





- (2) Separate them automatically immediately after the current began to flow.
- (3) Feed the carbons as fast as they were consumed so that the points would not become too widely separated.
- (4) Short-circuit any lamp whose carbons were entirely consumed or which for any reason failed to operate. This last feature was necessary since most arc lamps were operated on series circuits where current flowed from one to the other and where the failure of any one lamp would otherwise have extinguished the entire series.

Many arc lamps of the multiple type were and still are used for projection purposes, chiefly in motion picture theatres and in searchlights. On multiple circuits it is necessary to provide not only regulating mechanisms for the carbons but a ballast resistance or reactance to limit and steady the flow of current. The ballast may consume as much as one-third to one-half the power consumed by the arc itself and hence has a marked influence upon its efficiency.

The earlier type of arc lamp was known as the "open arc"

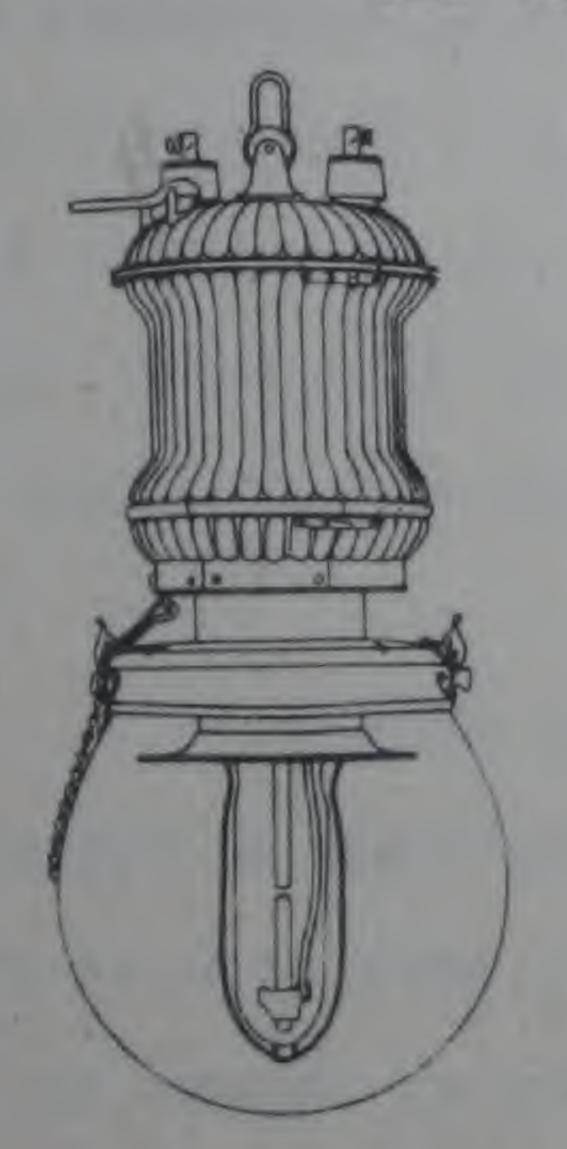


Fig. 6 - Arc Lamp

exposed to the atmosphere. While this lamp was very efficient in comparison with other illuminants of its day and was widely used for street lighting, no redirector was provided to utilize the light normally emitted upward. Consequently, it illuminated a relatively small area immediately adjacent to the lamp to a high intensity while at points a relatively short distance away the intensity was low. Moreover,

there was usually a dark spot immediately below the lamp due to the shadow cast by the lower carbon and its support.





An improved type of arc lamp was the enclosed arc wherein the arc was surrounded by a glass globe. Although not airtight, the enclosing globe prevented free access of air to the electrodes with the result that the consumption of the carbons was greatly retarded. While the enclosed arc did not give as much light for the same wattage as the earlier type of open arc, it was unnecessary to make as frequent renewals of the carbon electrodes. As a result it was extensively used for street lighting.

In the original carbon arc lamp, the hot gases in the arc gave off about 10 percent of the total light and the remaining 90 percent was emitted by the heated carbon electrodes. Later, it was found that if the electrodes were impregnated with certain salts, the arc gases became highly luminous. Thus, for a given amount of electrical energy, the so-called flaming arc lamp which resulted from this impregnation furnished considerably more light. These lamps were handicapped by the necessity for frequent carbon renewals.

Attempts were made to enclose the flaming arc by providing a condensing chamber to remove the solid products of the combustion
of the electrodes, but in spite of this a coating formed on the globes
and in some cases the globes became roughened or pitted. Because high
initial efficiency of these lamps could not be maintained, they did not
prove particularly economical and therefore gradually disappeared from
use.

More light from the arc was also obtained by using electrodes of materials other than carbon, a notable example being the Magnetite arc, some of which are still in use. In the Magnetite arc a bar of copper is used for one electrode. The other electrode is a thin steel tube containing a composition of Magnetite. Magnetite arcs are of high efficiency. The electrodes are not consumed rapidly, hence they require infrequent trimming. The light emitted is relatively white in color.





## The Mercury-Vapor Lamp

Another lamp, widely used for photographic purposes and to some extent for industrial lighting, is the Mercury-Vapor lamp, which can be recognized by the characteristic bluish green color of the light. This lamp consists of a long glass tube from which the air has been exhausted and which contains a small amount of mercury in a bulb at one end. An electrode is sealed into the glass at either end of the tube. The arc is started by tilting the tube slightly until a thin stream of mercury completes the circuit between the terminals. Returning the tube to its normal position breaks the circuit as the mercury runs back into the bulb and draws an arc behind it. The heat of the arc soon vaporizes enough mercury to fill the tube and it becomes luminous throughout its entire length. The peculiar color of the light is due



Fig. 7 - Mercury Vapor lamp

to the presence of a relatively high percentage of green and blue rays and to the absence of red rays. Since photographic emulsions are most sensitive to green and blue, the mercury vapor arc is an efficient illuminant for photographic purposes.

#### The Neon Tube

When an electric current is forced through certain gases, they become luminous. Neon, one of the rare elements of the atmosphere, is a gas of this type which glows with a rich orange-red light. The Neon tubes used in electrical advertising operate on this principle.





other desired patterns and an electrode is sealed into each end. They are then carefully exhausted of air and a small quantity of Neon admitted. Due to the high resistance of the gas, voltages of from 8000 to 12,000 volts are required to operate the tubes. Colors other than the characteristic orange-red are obtained by introducing small quantities of other gases such as mercury vapor, argon, and carbon dioxide and by making the tubes of colored glass.

Neon tubes have a bright, vivid, day and night appearance. They consume a relatively small amount of current but have a rather low power factor (about .50).

# Hot Cathode Neon Lamps

A recent development in gaseous conductor tubes is the so-called "Hot Cathode Tube". In this device one of the terminals is heated to incandescence. This allows the lamp to operate at a considerably lower voltage and provide a better efficiency in terms of light output per watt of energy consumed. Tubes of this kind have been used for spectacular lighting and for the floodlighting of buildings.

#### THE INCANDESCENT LAMP

#### Early Experiments

Sir Humphrey Davy who discovered the arc lamp, experimented with the incandescent lamp as early as 1802. He connected wires of different metals between the terminals of a battery. These became hot and emitted light but, except for platinum, each was oxidized and consumed before it reached a point where any useful amount of light was obtained.

Many experimenters made incandescent lamps of various types of construction and with different filament materials. It was not until 1879, however, that the experiments of Thomas A. Edison resulted in a practical and commercially successful incandescent lamp.





# Carbon Filament Lamps

The essential elements of the early carbon lamp consisted of -

- (a) A high resistance carbon filament made from a piece of carbonized sewing thread.
  - (b) An all glass enclosing bulb.
  - (c) A high vacuum in the bulb.
- (d) Platinum wires sealed through the glass to conduct the current to the filament.

of previous experimenters but in the form of short, thick pieces of relatively low resistance. The use of carbon was dictated by its high melting point which permitted the filament to be heated to a point where it emitted light efficiently without melting or disintegrating too rapidly. In 1880 the filament made from carbonized sewing thread was replaced by that made from carbonized strips of bristol board or paper, and this was in turn soon replaced by carbonized bamboo fibres.

#### The Treating Process

One of the chief troubles with carbonized threads or fibres was their lack of uniformity. Certain sections of the filament would be smaller in diameter than others, causing them to operate at a higher temperature and to burn out at these points. A patent of the Sawyer Mann Electric Company, the forerunner of the Westinghouse Lamp Company, covered the so-called "treating" process, whereby the filaments were lighted in jars containing gasoline vapor. The gasoline was decomposed at the smaller and hotter sections of the filament, depositing carbon there and building up the filament to a uniform thickness. This process made it possible to manufacture lamps which produced light more efficiently and at the same time had longer life.





# Carbonized Cellulose Filament

In 1893 the bamboo filament was superseded by carbonized cellulose filament. Cotton or other forms of cellulose was dissolved to the consistency of a thick syrup and squirted through a die after which it was solidified to form a thread - a process similar to that now used in the manufacture of artificial silk. These threads were cut to the desired length, formed to the proper shape and carbonized by the same process used for bamboo filaments. One of the advantages of the cellulose filament was the fact that it could be made to any desired length whereas the length of bamboo filaments was limited by the distance between joints of the bamboo stick.

## Metallized Carbon Filament

In 1905 metallized carbon filaments were marketed. The squirted cellulose filament, after carbonization and treating with gasoline vapor, was subjected to a subsequent intense heating in an electric furnace. The carbon deposited by the treating process assumed a graphite-like structure with some of the properties common to metals. It was, therefore, called metallized filament and such lamps were in general use until superseded by tungsten filament lamps in 1907. The manufacture of metallized filament lamps was discontinued entirely in 1918.

#### Metal Filament Lamps

While carbon has an extremely high melting point and from that standpoint is ideal for incandescent lamp filaments, it is subject to the serious disadvantage of evaporating or disintegrating at a temperature far short of its melting point. Since the light output of an incandescent lamp is directly proportional to the operating temperature of its filament, this characteristic of carbon placed a definite limitation upon its use as a filament and stimulated search for other materials which would withstand higher operating temperatures. A large





number of different metals were used experimentally but only a few were practical. Among these were osmium, tantalum, and, finally, tungsten. Neither osmium nor tantalum were commercially acceptable due to the extreme fragility of the filaments after they had once been burned.

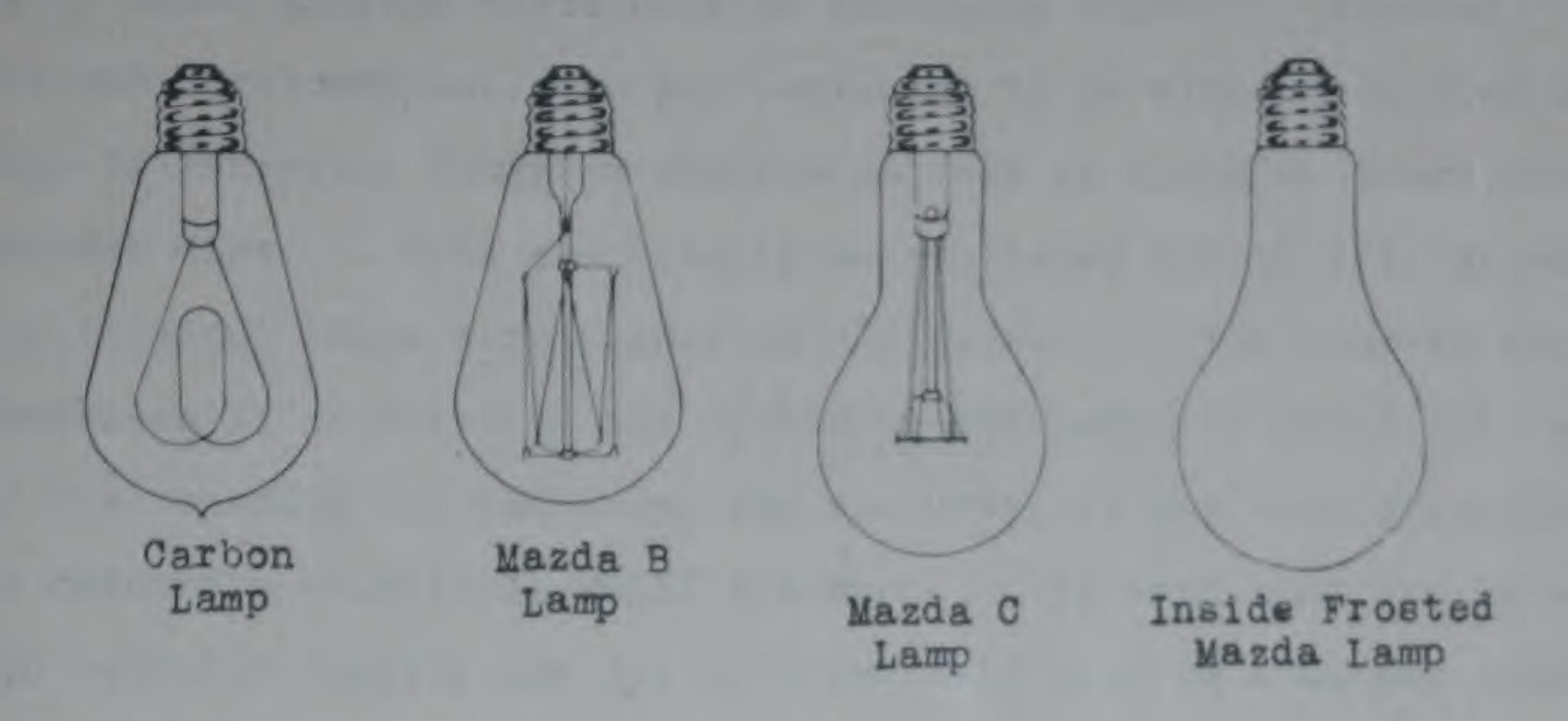


Fig. 8 - Types of incandescent lamps.

#### Tungsten Filament Lamps

Tungsten, the metal now used for Mazda lamp filaments, was introduced commercially for that purpose in 1907. It is an extremely heavy metal, nearly twice as heavy as lead. Tungsten ores are found in China, British Burma, and in this country in Colorado. It has an extremely high melting point (5700° F.) and evaporates much more slowly than carbon at corresponding temperatures.

The early use of tungsten for filaments was greatly retarded by its high melting point and by its hardness and brittleness. It could not be melted in crucibles like other metals or, at that time, be drawn into wire. For this reason, it was necessary to make a paste of the powdered metal with a binding substance and squirt it thru a die in much the same manner as the squirted cellulose filaments were made. The binding material was then driven out by passing a current thru the filament and heating it while in an atmosphere of hydrogen and nitrogen pases. This left the tungsten behind in the form of a





wire which, although extremely brittle, could be used for lamp filaments.

# Drawn Tungsten Wire Filaments

In spite of the fragility of the squirted (also called "pressed") tungsten filament lamps, they were adopted quite rapidly because of their greater efficiency in producing light. However, research and developmental work was continued in an attempt to find ways and means of rendering tungsten ductile so that it could be drawn into wire through dies. This was finally accomplished and in 1911 drawn tungsten filament lamps were placed on the market. The process consists essentially of pressing and sintering the powdered metal into a bar and then swaging and hammering the bar until it has been elongated and has reached a relatively small diameter. By that time the metal has been rendered ductile and can be drawn into wire in a manner similar to other metals. Tungsten wire is now drawn to sizes so small (0.0006") that it would require four pieces to equal the thickness of a human hair.

# "Getters"

While tungsten does not evaporate nearly as rapidly as carbon and may be operated at higher temperatures and more efficiently, yet it does evaporate and form a black, light-absorbing film on the inside of the glass bulb. Various "getters" were, therefore, developed, chemicals which are placed inside the bulbs to perfect the vacuum and to either combine chemically with the evaporated tungsten or physically break up the film to render it less opaque. These "getters" have been so perfected that a vacuum lamp may be burned for 1000 hours or more without showing appreciable blackening, whereas without "getter" they would blacken in three hundred hours.

#### Gas Filled Lamps

The introduction of gas filled lamps in 1913 represented another "getter" development along radically different lines. Heretofore,





whereas the introduction of an inert gas into the bulb was for the purpose of retarding the evaporation. This, however, presented further problems. The gas conducted heat away from the filament so rapidly that little or no increase in efficiency was obtained until the filament was coiled into a tightly wound "helical" spring. In this way, the surface exposed to the circulating gas was materially reduced and a much more efficient lamp obtained.

The first gas-filled lamps of the 115 volt range to be introduced were 750 and 1000 watt lamps in 1913, these were followed by the 500 watt size, the 200 and 300 watt sizes, and the 100 watt size, in 1915; the 75 watt size was made in 1916. The larger sizes appeared first because the large filament wire is more easily handled and because the gain in efficiency by the use of gas in the bulb is greatest. the diameter of the wire is decreased, its surface area in proportion to its cross sectional area increases rapidly. For this reason, the cooling effect of the gases is greater in the lower wattage lamps having a relatively fine filament and hence a greater percentage of energy supplied to the filament is lost in the form of heat instead of being utilized as light. A point is finally reached where the heat loss offsets any gain in light output which may be brought about by increased filament temperature and a vacuum lamp becomes the more efficient type. At present, the smallest gas filled lamp in the 115 volt range which can be made efficiently is the 50 watt size, while, for sizes below this, the vacuum type is more efficient. Development work is being continued, however, on smaller sizes and it is quite possible that a 40 watt gas filled lamp, more efficient than the present 40 watt vacuum lamp, will be perfected.

Nitrogen, an inert gas which forms approximately 20 percent of the atmosphere, was first used in the gas filled lamps but argon, one of the rarer inert gases which forms only 0.9 of one percent of the





atmosphere, has been in general use since 1920. Argon does not conduct heat as rapidly as nitrogen and therefore permits the lamps to be operated more efficiently. In practice, a mixture of approximately 85% argon and 15% nitrogen is used. Pure argon conducts electricity under the conditions existing in electrical incandescent lamps and would short-circuit the filaments if used alone.

It should be borne in mind that the size of wire used, and not the wattage, determines whether a lamp can be of the gas-filled type. For example: a 15 watt 30 volt gas-filled lamp is more efficient than the corresponding vacuum type - this, because, a filament of about the same size as that in a 60 watt 120 volt lamp is used. Generally speaking, a lamp whose filament carries less than 0.4 amperes is more efficient in the vacuum type.

# Coiled Filament Vacuum Lamps

A part of the development of gas-filled lamps was the perfection of machines and methods for winding the filament wire. In the original gas-filled lamps of the larger sizes the filament was relatively coarse and the crude winding machines available at that time were satisfactory. But as it became necessary to coil wire of smaller and smaller diameter for the lower wattage lamps, it became necessary to develop coil winding machines of greater accuracy and precision until today such machines are capable of coiling tungsten wire smaller in diameter than a human hair. Experience revealed that there were many advantages in the use of coiled filaments over straight filaments. As a result coiled filaments are also used in lamps of the vacuum type. At present the manufacture of straight or loop filament lamps has been practically discontinued.

#### Daylight Blue Bulb Lamps

The light from an incandescent filament is relatively richer in red and yellow rays and poorer in green and blue rays than is





average daylight. The object of daylight blue bulbs is to absorb some of the excess red and yellow rays while transmitting the green and blue rays from the incandescent filament so that the resulting light approaches average daylight in color value. Such bulbs absorb approximately 35 percent of the light emitted by the filament and therefore should not be used except in cases where color value is of sufficient importance to warrant this sacrifice of light.

absorb still more of the red rays which have little or no effect upon photographic emulsions. These lamps, however, freely transmit the blue rays having the greatest photographic action.

# Inside Frosted Bulb Lamps

The adoption of coiled filaments for the smaller sizes of lamps concentrated the light source into a small area and incandescent lamps thus tended to became sources of objectionable glare. Several different developments were made in an attempt to overcome this objectionable feature. Clear glass bulbs were frosted and etched and bulbs of opal glass were also used. The object of these was to increase the effective size of the light source by rendering the entire bulb luminous rather than the small area of the filament. Such methods were unsatisfactory, however, because of the sacrifice in the amount of light absorbed which varied from 8 percent to 20 percent, depending on the type of diffusing medium used. By frosting the inside of a lamp bulb. the desired diffusion was accomplished with the loss of only 1 to 2 percent of the light. This process was adopted in 1925 for lamps from Lamps of larger size are ordinarily used in light-15 up to 100 watts. ing units suspended high enough to be out of the direct line of vision or are used in enclosing glass globes which diffuse the light. Further, the brilliancy of these larger filaments is so great that better diffusing mediums than frosted glass are required for the most satisfactory results.





# Efficiencies of Various Types of Incandescent Lamps

The efficiency of incandescent lamps is generally expressed in terms of lumens of light produced per watt of energy consumed.

The improvement which has been made since the first commercial carbon filament lamps is indicated in the following table:-

	Type of Lamp	E	fficiency		
1879	First Commercial Lamps	1.4	lumens/	watt	
1893	Carbonized Cellulose	3.3	**	99	
1905	Metallized Carbon	4.0			
1906	Tantalum	4.8	11	-	
1907	Pressed or Squirted Tungsten	7.9	**	**	
1911	Drawn Tungsten Wire	10.0	12	11	
1913	Gas-Filled 100 Watt	12.6		- 11	
1926	Inside Frosted 100 Watt*	13.2	**	99	

\*The efficiencies of some of the larger Mazda lamps available today are as high as 26 lumens per watt.

#### DEFINITIONS OF ELECTRICAL TERMS

# Volt (Unit of Pressure)

The volt is the unit of electrical pressure corresponding to pounds per square inch of water or air and is named after Alesandro Volta who discovered the chemical means of generating electricity. One volt is the electrical pressure or electromotive force generated by a standard cell or battery constructed in a standardized way of carefully specified materials.

# Ampere (Unit of Quantity)

The ampere is the electrical unit of quantity or volume corresponding to cubic feet per minute or gallons per minute for water or air. Technically, it is the amount of electricity which will deposit 0.001118 grams of silver in one second from a standard silver





nitrate solution. It was named after Andrae Ampere, Professor of Mathematics in the Polytechnic School of Paris.

# Watt (Unit of Work)

The watt is the electrical unit of work corresponding to horse-power and was named after John Watt inventor of the Steam Engine. It is the product of volts x amperes (pressure x quantity). Just as a small quantity of water under high pressure will do as much work as a larger quantity of water under a correspondingly lower pressure, so a current of a few amperes under a high voltage pressure will do as much work as a higher current at a correspondingly lower voltage. For example: current of 2 amperes at a pressure of 100 volts will do as much work as a current of 4 amperes at 50 volts, the wattage in each case being 200. One horse-power is equivalent to 746 watts. The kilowatt is 1000 watts.



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## QUESTIONS

- 1. List briefly the development of illuminants from the torch to the modern Mazda lamp.
- 2. What are the principal advantages of the Mazda lamp over the illuminants which it superseded?
- 3. Explain the essential differences between the carbon, the vacuum, and the gas-filled lamp.
- 4. If the use of an inert gas in a lamp retards the filament evaporation and the bulb blackening, why it is not used in all types of Mazda lamps?
- 5. If an imported carbon lamp costing 10 cents gives the same amount of light as a 25 watt Mazda lamp costing 20 cents, which, during a period of 1000 burning hours, would be the cheaper for the user? Why should carbon lamps be refused at any price?

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